

(19)



Europäisches Patentamt

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(11)

EP 0 752 748 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
08.01.1997 Bulletin 1997/02

(51) Int. Cl.⁶: H02J 7/10

(21) Application number: 95830239.0

(22) Date of filing: 07.07.1995

(84) Designated Contracting States:
DE FR GB IT

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(54) **Multiple function battery charger, self-configuring as supply voltage regulator for battery powered apparatuses**

(57) Regulation of the output supply voltage to a load powered by a rechargeable battery of a portable apparatus, typically a telephone, is advantageously implemented by exploiting the switching STEP-DOWN REGULATOR of an in-built battery charger. The regulator circuit configures itself in function of the voltage level at the regulator input to retain an unmodified constant current and constant voltage battery charger function as

long as a sufficiently high (recharge) voltage source is connected to the input. Otherwise the battery voltage is applied to the input of the regulator and configuring means modify automatically the partition ratio of an output voltage sensing divider of the voltage-mode control loop of the charger, isolate the battery pole from the output and disable the current-mode control loop of the charger.

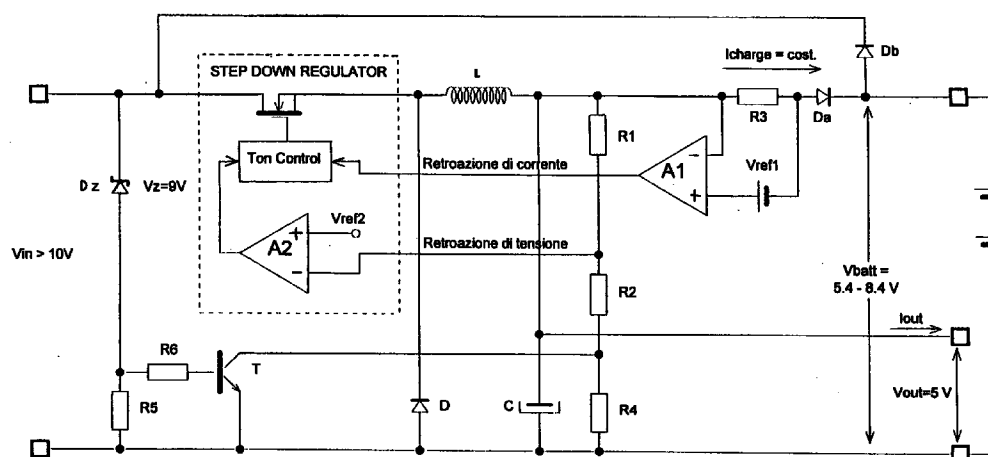


FIG. 2

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Description

This invention is concerned with a battery charger system for portable electronic apparatuses, functioning in a switching mode under constant current and constant voltage control modes, which is also structured as a supply voltage regulator for the portable apparatus circuit.

Lithium rechargeable batteries (lithium ion or lithium metal batteries) provide for higher performances compared to those of NiCd or NiMH rechargeable batteries, for example in terms of a greater capacity, expressed in Ampere-hour, for the same volume and in terms of a charge characteristic that does not require particular contrivances in order to avert overcoming the maximum permissible charging condition.

By contrast, a lithium cell voltage varies considerably according to its state of charge, going from a minimum of 2.7 Volts (completely discharged cell) to a maximum of 4.2 Volts (fully charged cell). In some conditions of use, as for example in the case of portable telephones, the supply voltage required for the circuits that constitute the load of the powering lithium batteries may be nominally 5.0 Volts. In this case, the battery pack must contain at least two cells and therefore the battery voltage can vary between 5.4 Volts (completely discharged battery) and 8.4 Volts (fully charged battery). This broad range of variation of the battery voltage may represent a critical parameter and become dangerous to the integrity of the powered integrated circuits.

In many applications involving lithium or other type of rechargeable batteries, in order to avoid excessive supply voltage conditions in case of a fully charged battery, it might be necessary to interpose a voltage regulating circuit between the battery and the load circuits so that the latter be powered at an almost constant supply voltage, lower or at most equal to the minimum voltage of a substantially discharged battery, regardless the battery state of charge. The necessity of a voltage regulator is even more stringent in the case of a load electronic circuit that has to be necessarily powered at nominally 3 Volts, as required by modern electronics systems of elevated scale of integration.

Naturally this implies the inclusion of an appropriate dedicated circuit, downstream of the rechargeable battery, in the portable apparatus. In addition, many apparatuses also incorporate the entire battery charger system or at least a control circuit of the constant current charging process and of the constant voltage trickle charging process for preventing damage of the battery if left under charge after reaching a certain maximum charge cell voltage.

Scope of the present invention is that of providing a dual-function, unified system for charging the battery by normally controlling the charging current (constant current control mode) until reaching a state of substantial charge of the battery and thereafter the voltage (constant voltage control mode) when the charge process is practically completed, which, upon disconnection from

the mains or from any other suitable external source of a recharging current, is capable of configuring itself automatically so as to perform as a voltage regulator of the voltage supplied to the battery-powered circuits (load), and viceversa upon connection to the external electrical source.

In practice, a unique regulation system automatically configures itself as a battery charger and as supply voltage regulator, thus reducing drastically the number of components used and costs.

The possibility of obtaining a dual recharger and regulator function by a unique electronics system promotes integration of the battery charger system in the portable apparatus, exploiting the same control circuit for regulating the supply voltage of the functional circuits of the apparatus.

Of course, the dual function system of the invention can also be useful in NiCd or NiMH batteries powered apparatuses or using any other type of rechargeable batteries that because of their characteristics require regulation of the supply voltage for compensating cell voltage variation in function of the state of charge.

Substantially this invention consists in employing the same STEP-DOWN switching mode regulator of a battery charger circuit, typically controlled by a first current-mode feedback loop and by a second voltage-mode feedback loop, by applying to the regulator input the battery voltage, when the functional circuits of the portable apparatus are being powered by the battery, while automatically disabling the current-mode feedback loop and exploiting the voltage-mode feedback loop, modifying the ratio of the output voltage divider thereof so as to regulate the output voltage at the value required by the powered circuits.

Configuration of the circuit as battery charger or as voltage regulator is automatic upon the application of a voltage higher than a certain minimum value related to the type of battery for charging the battery or its disconnection from the input node of the STEP-DOWN regulator, respectively.

These and other aspects and advantages of this invention will be more evident through the following description of an important embodiment and by referring to the annexed drawings, wherein:

Figure 1 shows a basic scheme of a constant current and constant voltage battery charger circuit;

Figure 2 shows a dual-function circuit realized according to the present invention.

It is common knowledge that a battery, for instance a lithium battery, can be charged by a preestablished constant current. During the charge, the battery voltage V_{batt} (for example for a two cell battery pack) rises from a minimum value of about 5.4 Volts (initial value at completely discharged battery) up to a maximum value of about 8.4 Volts. It is very important not to go over 8.4 Volts in order not to compromise the cells integrity.

Therefore, once the preestablished maximum value

of the battery voltage is reached, which in the case of a lithium battery can be of 8.4 Volts, the charging system must switch from a mode of operation as a generator of a constant current to a mode of operation as a source of a constant voltage. Charging of the battery continues also during this terminal phase of the charging process at a constant voltage. In this phase, the current absorbed by the battery gradually drops to zero. In this way, the battery may remain coupled to the electrical recharging source indeterminately (eventually absorbing a trickle current) without any negative effect on its integrity.

A typical battery charger circuit is shown in Fig. 1.

The circuit, as indicated in Fig. 1, substantially comprises a STEP-DOWN switching regulator, a current limiting inductor L, a filter capacitor C, a current recirculation diode D for discharging the inductor L during an nonconductive phase of the power switch of the regulator.

The conduction interval (duty-cycle) of the switch, which as shown in the scheme of Fig. 1 may be an isolated-gate power MOS transistor, controlled by a driving logic circuit Ton Control. The regulation of the duty-cycle is effected by employing a first current-mode feedback loop, composed of a sensing resistance R3 for monitoring the charging current and a first A1 error amplifier, the signal produced by which is processed by the control logic circuitry Ton Control.

The loop regulates the charging current in function of a predefinable value set by Vref1, during the battery charging process up to reaching a maximum charge voltage set by Vref2.

When this preestablished maximum battery voltage Vbatt is reached, the second voltage-mode feedback loop, composed of a voltage divider R1-R2 of the regulated output voltage and a second error amplifier A2, whose output signal is processed by the control logic circuitry Ton Control, takes over the control of the switch duty-cycle, so as to keep constant the output voltage of the STEP-DOWN regulator at the preestablished value (in other words at a value equal to the maximum admissible battery voltage).

The input voltage Vin of the battery charger can be a nonregulated rectified voltage, or a car battery voltage, whose value must necessarily be higher than the maximum charge voltage of the battery pack. The non-regulated input voltage Vin can be the filtered output voltage of a rectifying diode bridge, coupled to the secondary of a transformer or any other DC voltage source of a voltage higher than the maximum charge voltage of the battery pack to be charged.

The embodiment of this invention for a conventional case of a battery charger circuit as the one shown in Fig. 1 is depicted in Fig. 2.

This example shows the case of a lithium battery pack composed two cells, where the battery voltage Vbatt varies from about 5.4 to about 8.4 Volts and the nonregulated input voltage Vin of the switching step-down regulator must be higher than about 10 Volts.

Exactly as in the case of the circuit of Fig. 1, the two feedback loops, of the constant current and constant voltage control modes, that control alternatively the duty-cycle of the STEP-DOWN regulator switch, that is the periodic conduction interval Ton of the power MOS transistor during which the Vin input voltage is applied directly to the inductance L, implement initially a regulation of the charging current and, during a conclusive phase of the charging process, a regulation of the charging voltage.

When the switch is in not conducting, the energy stored in the inductance L is discharged by recirculating a current through the diode D.

During a conduction interval Ton, the current that flows in the inductor L grows linearly with time according to the equation:

$$I = \frac{(V_{in} - V_{batt}) T_{on}}{L} \quad (1)$$

In view of the fact that Vin can be an inconstant voltage and that Vbatt varies according to the state of charge of the battery, the regulation of the charge current I takes place by suitably regulating the time interval Ton so as to cause the system to deliver a constant current that can be set by adjusting the value of Vref1.

To this purpose, the current-mode feedback loop senses continuously the voltage drop provoked by the current I on the resistance R3. Such a drop is compared with a reference voltage Vref1 and the difference is amplified by the error amplifier A1 that acts directly on the time Ton of the STEP-DOWN REGULATOR in order to fulfill the following relation:

$$I \cdot R3 = V_{ref1} \quad (2)$$

that is keeping the current I constant.

By combining equations (1) and (2), we obtain:

$$T_{on} = \frac{V_{ref1} \cdot L}{R3(V_{in} - V_{batt})} \quad (3)$$

where it can be noticed that Ton must always be inversely proportional, instant by instant, to the voltage difference Vin-Vbatt.,

During the charging, the battery voltage Vbatt increases in time. Such a voltage is sensed continuously by means of a resistive voltage divider R1, R2 and compared with a reference voltage Vref2.

When the equation below is satisfied:

$$\frac{V_{batt} \cdot R2}{R1 + R2} = V_{ref2} \quad (4)$$

the error amplifier A2 acts on the time Ton of the STEP-DOWN REGULATOR in such a way as to fulfill the equation (4), thus keeping constant the voltage Vbatt.

It can be demonstrated that in this functioning mode at a constant voltage, the relation that ties Ton to the

preestablished maximum charge value of the battery voltage V_{batt} is:

$$T_{on} = \frac{V_{batt}}{V_{in}} \cdot T \quad (5)$$

where T is the period of the switching frequency of the regulator that may commonly be from ten to several hundreds KHz.

Therefore the time T_{on} is regulated by the current-mode feedback loop, according to equation (3), during a phase of delivery of a constant current and by the voltage-mode feedback loop, according to equation (5), during a phase of providing a constant output voltage.

The two feedback loops "act" alternatively, in function of the voltage V_{batt} .

As it can be observed, during a battery charging phase, that is when to the input of the regulator is applied a voltage V_{in} sufficiently high, the functioning of the battery charger system of the invention shown in Fig. 2 is at all similar to that of the normal circuit of Fig. 1.

Indeed, being the input voltage V_{in} greater than the voltage output by the STEP-DOWN regulator (of the battery charger output), the diode D_b is reversely biased and therefore totally influent. Moreover, due to the persistence of a voltage ($V_{in} > 10V$) greater than a given value, the bias line constituted by the zener diode D_z and by the resistance R_5 , in which the zener voltage is lower than the minimum value of the input voltage V_{in} needed to charge the battery, keeps the transistor T in a conductive state so that it substantially short-circuits the resistance R_4 connected in series with the divider R_1 - R_2 of the regulated output voltage of the battery charger (See Fig. 1), making influent the presence of the resistance R_4 in relation to the normal functioning of the battery charger system.

Only the presence of an added isolation diode D_a , respect to the basic circuit of Fig. 1, must be accounted for by modifying appropriately the ratio between the resistances R_1 and R_2 of the output voltage divider in consideration of the voltage drop on the isolation diode D_a . In practical terms the following relationship should be verified:

$$V_{ref2} \left(1 + \frac{R_1}{R_2} \right) - V_{DA} - I \cdot R_3 = V_{batt} = 8.4 V \quad (6)$$

where V_{DA} is the voltage drop of the diode D_a due to the constant charge current I .

Therefore, by assuming substantially null the load of the battery during a recharging phase (that is in absence of a nonnegligible absorption of current by the battery powered load circuits), the functioning of the system in a battery charging phase is a replica of that of the basic circuit shown in Fig. 1.

When the battery charger is disconnected from the source of the input voltage V_{in} , the circuit configures itself as a regulator of the supply voltage V_{out} at which

the load circuits are powered, at a preestablished value, lower than the battery charge voltage ($V_{out} < V_{batt}$), as for example $V_{out} = 5V$.

Indeed, by not being any longer present an input voltage V_{in} greater than a threshold value ($V_{in} > 10V$), the battery voltage V_{batt} is applied through the now conductive diode D_b to the input node of the regulator STEP-DOWN REGULATOR, while the diode D_a , being reversely biased, blocks the flowing of a current along the charging line of the battery, through the sensing resistance R_3 , thus practically disabling the current-mode control loop of the system.

In addition, being the battery voltage V_{batt} lower than the zener voltage of the diode D_z , the latter is in an off condition and consequently the transistor T is also in an off condition. In these conditions, the resistance R_4 is effectively connected in series to R_2 , thus modifying the partition ratio of the output voltage sensing divider and therefore the error signal sensed by the amplifier A_2 of the regulator.

Therefore, the output voltage V_{out} will have a value given by:

$$V_{out} = V_{ref2} \left(1 + \frac{R_1}{R_2 + R_4} \right) = 5 V \quad (7)$$

The values of R_1 and R_2 must be chosen according to the equation (6) that fixes the battery maximum charge voltage during, while the value of R_4 is dictated by equation (7) that fixes the output voltage of the system as a regulator of the supply voltage.

Because $V_{out} < V_{batt}$, the diode D_a remains in a reverse bias state and therefore the battery voltage does not affect the output voltage V_{out} .

Therefore, the output current I_{out} is determined only by the characteristics of the load connected to V_{out} and eventually limited to a maximum value deliverable by the regulator STEP-DOWN REGULATOR.

By employing a diode D_b of the Schottky type, that is a diode with a particularly low direct voltage drop and a power switch of the STEP-DOWN REGULATOR realized with a low $R_{DS(on)}$ power MOS transistor fabrication technology, it is possible to maintain constant $V_{out} = 5V$ for the whole charge voltage range of a lithium battery (e.g.: 8.4 V_{max} , 5.4 V_{min}).

The circuit of Fig. 2 is capable to operate as a battery charger and as a output voltage regulator when powering the load circuits with the battery.

The same system, eventually provided with common sensing devices of the voltage characteristic changes of the battery with time and/or of the battery pack temperature during the recharge process, can be advantageously employed also for batteries of the NiCd and NiMH type. Clearly, the utility of the system of this invention is not limited to the case of lithium batteries.

Claims

1. A system for charging a battery at a constant cur-

rent during at least a first phase of the charging process and at a constant voltage during a conclusive or charge maintenance phase of the charging process by means of a charging circuit employing a STEP DOWN switching regulator, the switch duty-cycle of which being controlled by a first current-mode loop and by a second voltage-mode loop, and for powering a battery load at a regulated supply voltage, characterized in that consists in

using the same STEP-DOWN switching regulator of the battery charger for producing a regulated supply voltage output, by configurably applying the battery voltage to an input node of said regulator, disabling said first current-mode loop and regulating the duty-cycle of the regulator switch through said second voltage-mode loop while modifying the partition ratio of an output voltage sensing divider of the regulator by configurably connecting in series to the sensing divider a resistance which is short-circuitable via a transistor controlled by the level of the input voltage.

2. The system as defined in claim 1, characterized by applying the battery voltage to the input of said regulator by connecting a diode between the relative battery pole and the input node of the regulator and reversely biasing the diode during a battery recharging phase, when on the input node is applied a recharging voltage higher than the battery voltage.

3. The system as defined in claim 1, characterized by isolating said battery pole from an output node of the regulator during a load powering phase by connecting a diode between said output node and said battery pole and inversely biasing the diode during a phase of load powering and in absence of a recharging voltage higher than the battery voltage at said regulator input node.

4. A dual-function circuit for charging a battery and regulating the supply voltage delivered to the battery load comprising a step-down switching regulator (STEP-DOWN REGULATOR), a current limiting inductor (L), a filter capacitor (C), a current recirculation diode (D) for discharging the inductor (L) during a nonconducting phase of a switch of the regulator, a first current-mode control loop composed by a current sensing resistance (R3), a first error amplifier (A1) for controlling through a logic circuit (Ton Control) the duty-cycle of said switch in function of the voltage drop on said resistance (R3), a second voltage-mode control loop composed of a regulated output voltage sensing divider (R1-R2), a second error amplifier (A2) for controlling through said logic circuit (Ton Control) the duty-cycle of said switch in function of the output voltage, characterized in that comprises further

at least one resistance (R4) connected in

series to said voltage divider (R1-R2);

at least a first isolation diode (Da) coupled between said current sensing resistance (R3) and the relative battery pole;

at least a second diode (Db) coupled between said battery pole and an input node of said regulator (STEP-DOWN REGULATOR);

at least a transistor (T) for short-circuiting said resistance (R4) in response to the presence on said input node of a voltage higher than the battery voltage, controlled by a biasing line comprising at least a zener diode (Dz) and a resistance (R5) connected in series between said input node and a common potential node of the circuit.

5. The dual-function circuit as defined in claim 4, characterized in that at least said second diode (Db) is a Schottky diode having a relatively low direct voltage drop and said switch is a power MOS transistor of relatively low conduction resistance.

6. A portable telephone apparatus powered by a rechargeable battery pack, incorporating a battery charger, characterized in that said battery charger circuit is a dual-function circuit as defined in claim 4.

7. The portable telephone apparatus according to claim 6, characterized in that said rechargeable battery is a battery composed of at least two Lithium cells in series.

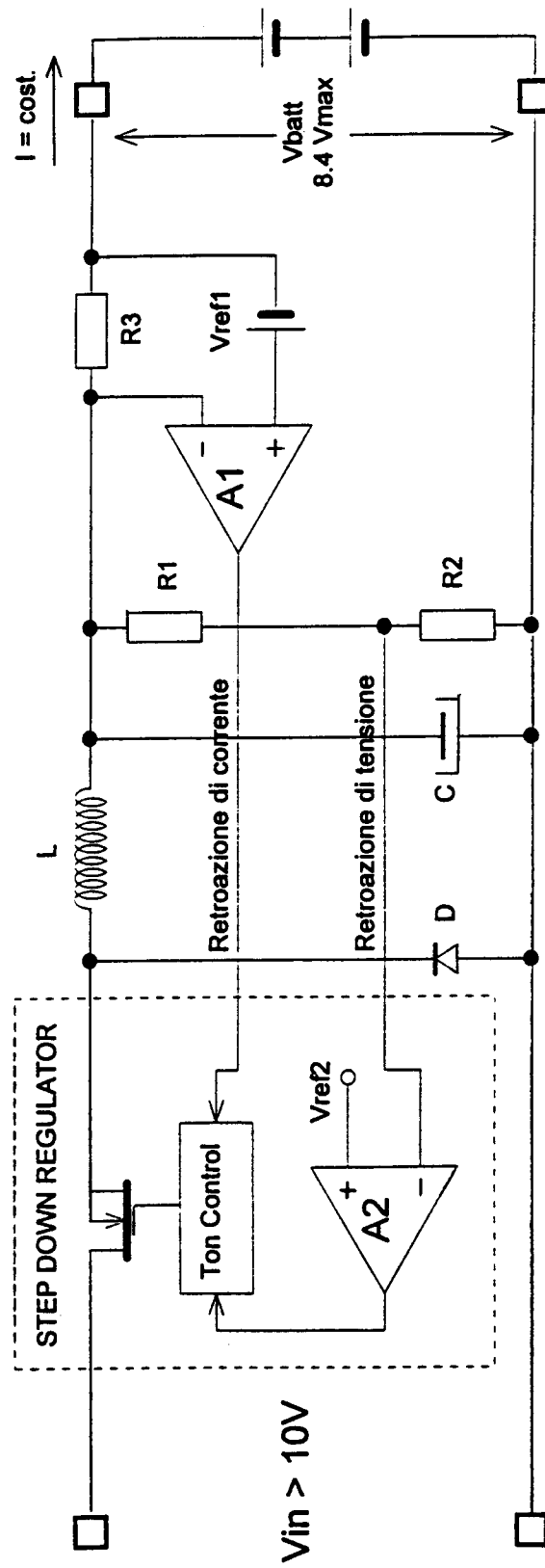


FIG. 1

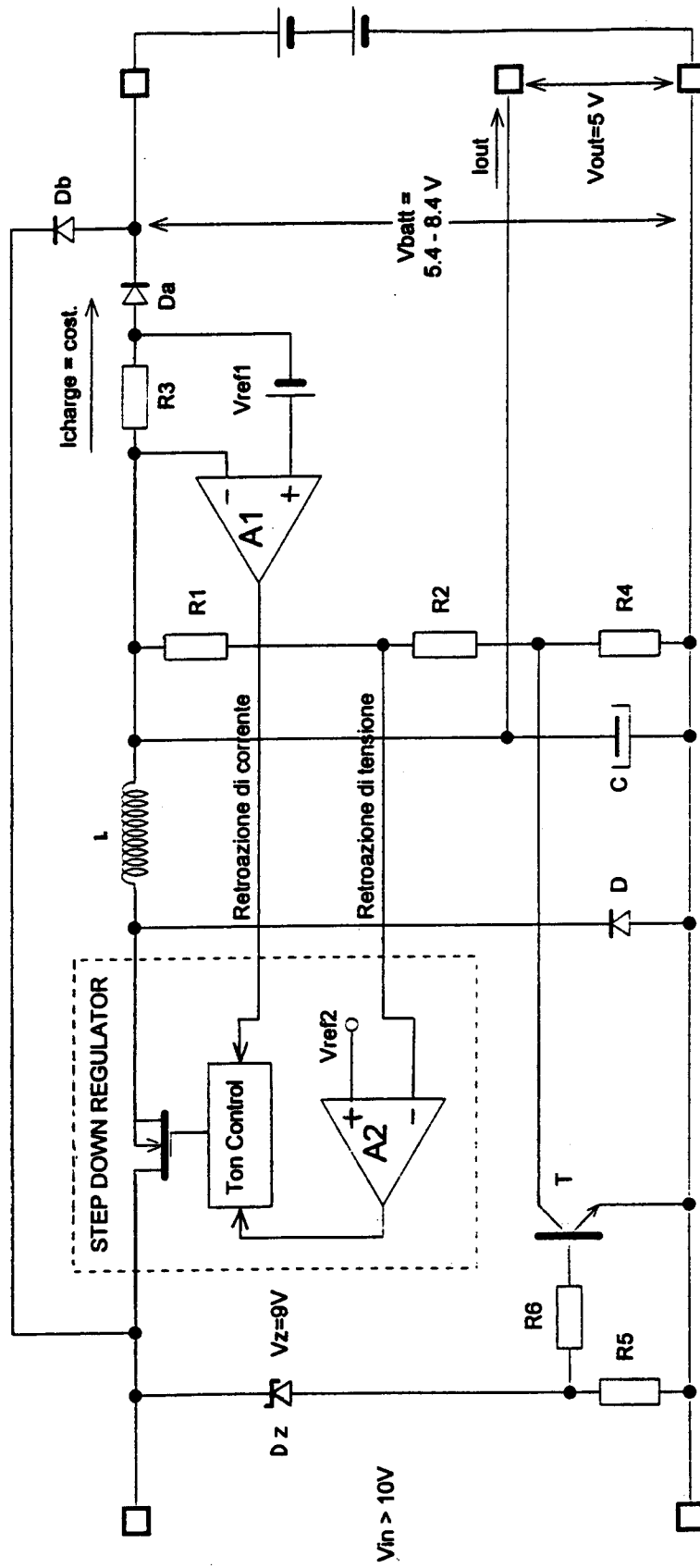


FIG. 2



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EUROPEAN SEARCH REPORT

Application Number
EP 95 83 0239

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	US 4 554 500 A (T.SOKIRA) * column 8, line 9 - column 9, line 35 *	1,4	H02J7/10
A	US 4 386 310 A (K.SIEVEFS) * the whole document *	1,4	
A	US 4 607 208 A (S.VREELAND) * column 2, line 51 - column 6, line 3 *	1,4	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			H02J
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 20 November 1995	Examiner KELPERIS K.
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